COPERNICUS ATMOSPHERE MONITORING SERVICE

PRODUCTS

Johannes Flemming (ECMWF)

WHAT IS COPERNICUS?

- Copernicus is **a flagship Space programme** of the **European Union**
  - to monitor **the Earth,** its environment and ecosystems
  - to ensure its citizens are prepared and protected for **security risks** and **natural or man-made environmental risks and disasters**
- Copernicus as **user-driven** Programme
- It has **full, free and open to all** data policy
- Is a tool for **economic development** and a driver for the **digital economy**
- Initiated in 1998, Copernicus became **operational in 2014**. Budget for 2014-2020 was **4.3 B€**. Foreseen budget for 2021-2027 is **5.8 B€**.

THE COPERNICUS SENTINELS

Copernicus

		Key Features
 SENTINEL-1: 4-40m resolution, 3 day revisit at equator	*S1A and 1B in orbit*	Polar-orbiting, all-weather, day-and-night radar imaging
 SENTINEL-2: 10-60m resolution, 5 days revisit time	*S2A and 2B in orbit*	Polar-orbiting, multispectral optical, high-resolution imaging
 SENTINEL-3: 300-1200m resolution, <2 days revisit	*S3A and S3B in orbit*	Optical and altimeter mission monitoring sea and land parameters
 SENTINEL-4: 8km resolution, 60 min revisit time	*1st Launch 2022*	Payload for atmosphere chemistry monitoring on MTG-S
 SENTINEL-5p: 7-68km resolution, 1 day revisit	*S5P in orbit*	Mission to reduce data gaps between ENVISAT, and Sentinel 5
 SENTINEL-5: 7.5-50km resolution, 1 day revisit	*1st Launch 2023*	Payload for atmosphere chemistry monitoring on MetOp 2nd Gen
 SENTINEL-6: 10 day revisit time	*1st Launch 2020*	Radar altimeter to measure sea-surface height globally

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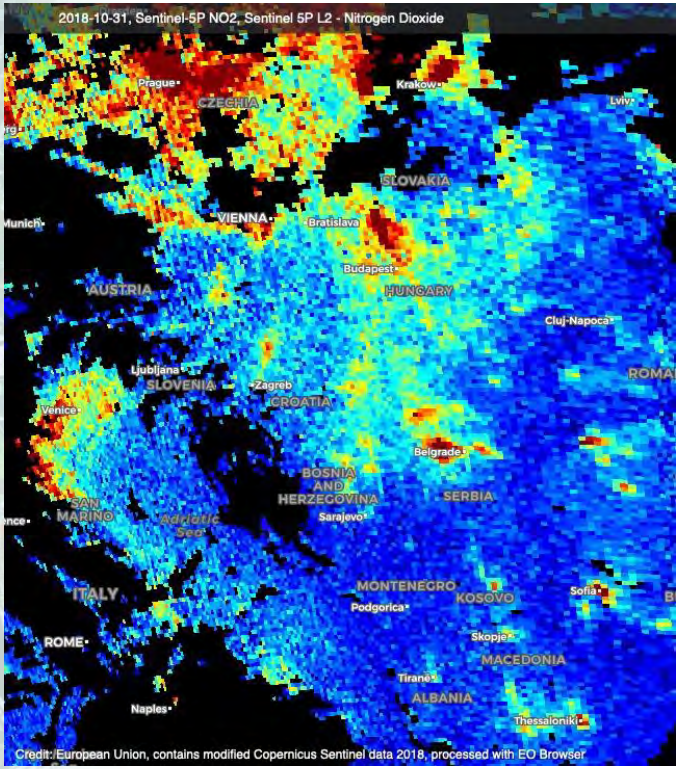
WHY INFORMATION SERVICES ARE NEEDED?



Example: NO_2 tropospheric column from Copernicus Sentinel-5P (31/10/2018)

Observations are essential, but **direct use** is generally **limited**:

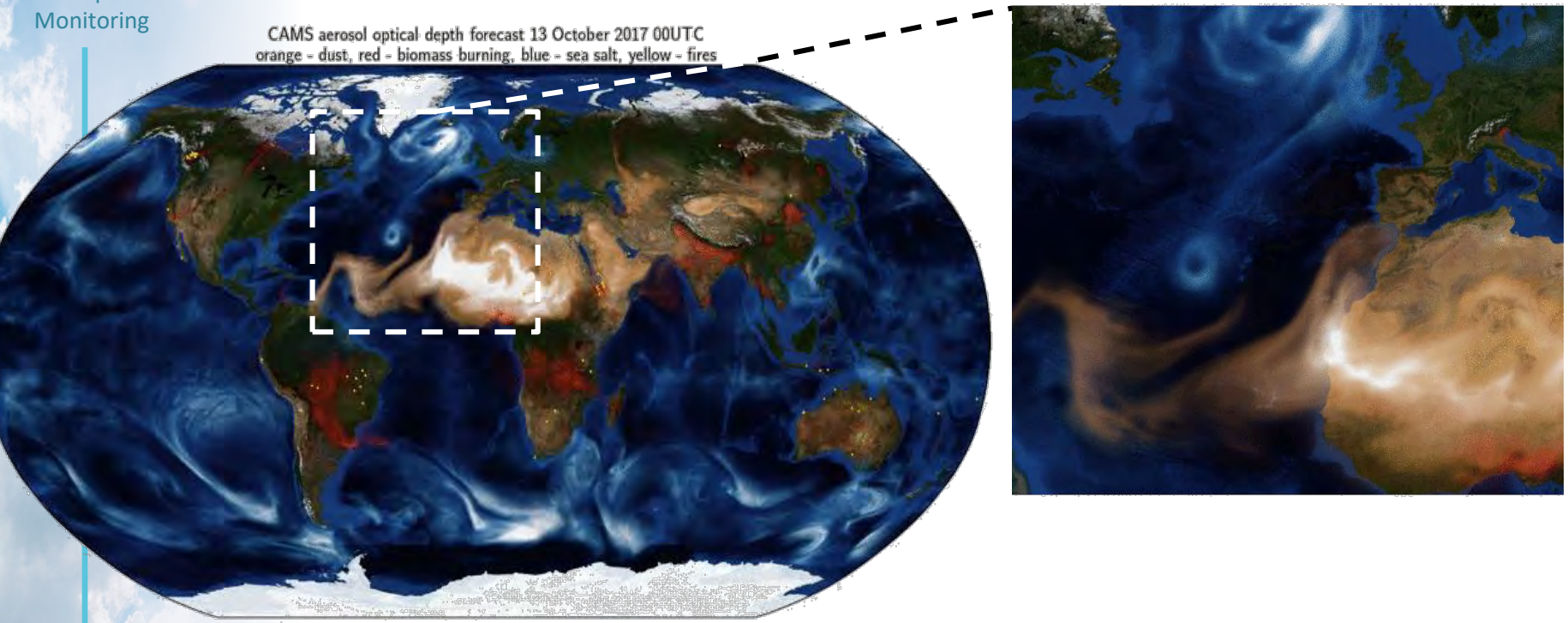
- gaps in space and time
- observed quantities may not be directly relevant (vertical column vs nose-level concentration)
- Complex and numerous

What services do:

- blend observations (satellite and non satellite) with model to provide a consistent “picture”
- forecasts, some days ahead
- reanalyses over past years, decades

COPERNICUS: EUROPE'S EYES ON EARTH

Atmosphere Monitoring



CAMS aerosol forecasts initialized on 13 October 2017. Storm Ophelia transported a mixture of smoke, dust and sea salt aerosol across Europe leading to the sun appearing red and to yellow skies.

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6 COPERNICUS THEMATIC SERVICES

Copernicus

Monitoring the State of the Earth System Environment ...

... Six cross-cutting Thematic Services

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Reactive gases data availability in CAMS NRT system

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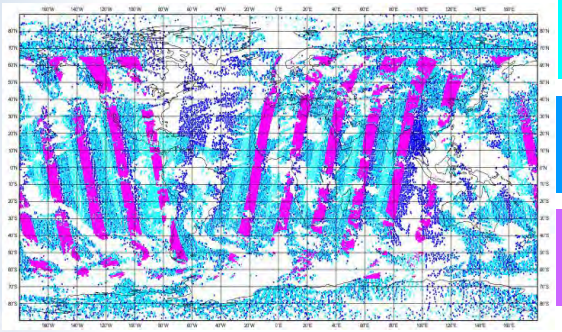
CO

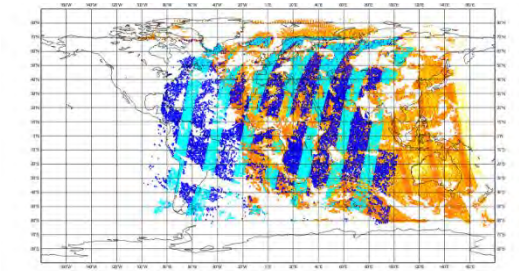


IASI Metop-A

IASI Metop-B

MOPITT TERRA

Tropospheric NO2



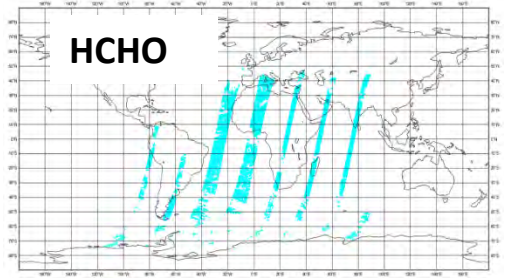
OMI AURA

TROPOMI S5P

GOME-2 Metop-A

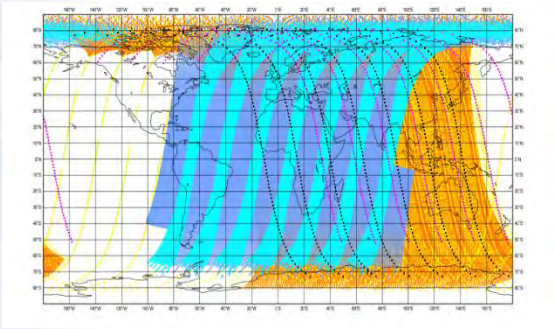
GOME-2 Metop-B

HCHO



GOME-2 Metop-A

O3



GOME-2 Metop-A

GOME-2 Metop-B

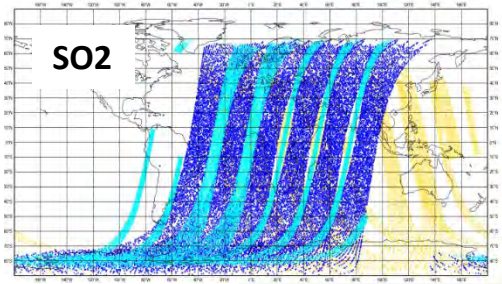
OMI, MLS AURA

SBUV/2 NOAA-19

OMPS SNPP

TROPOMI S5P

SO2



OMI AURA

GOME-2 Metop-A

GOME-2 Metop-B

assimilated

monitored

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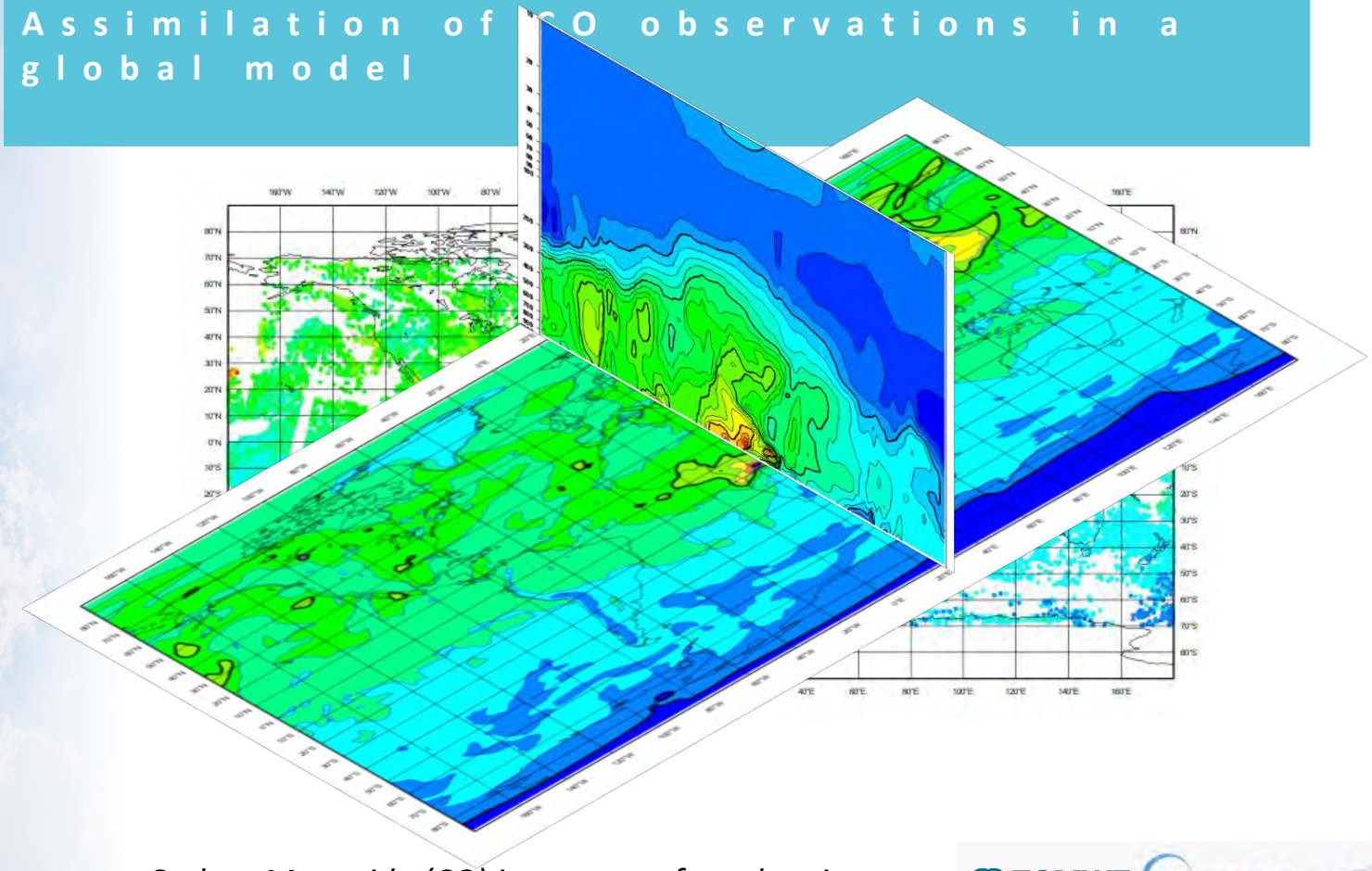
Assimilation of CO observations in a global model



Carbon Monoxide (CO) is a tracer of combustion sources

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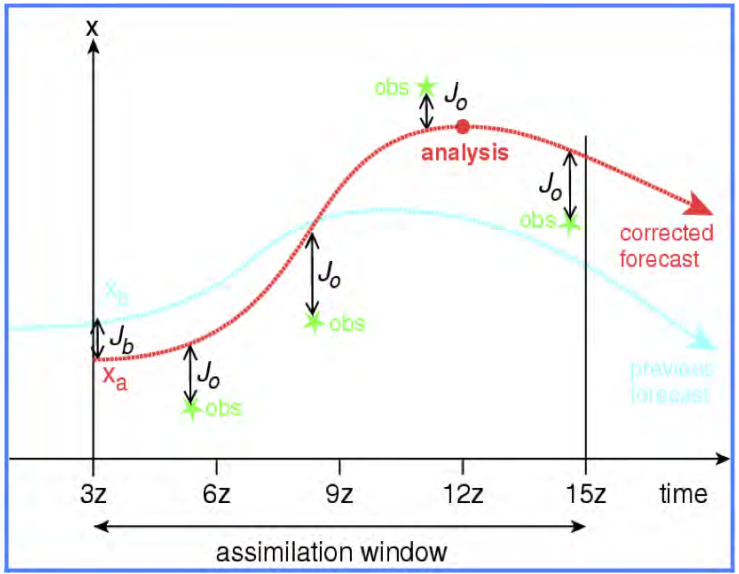
Motivation for combining observations with models

- We need an efficient means of combining the information from ~20,000 observations with a global model at ~40 km horizontal resolution.
- Data assimilation is the process of merging observations with a model in a statistically consistent manner.
- We want to minimize a cost function (J) that evaluates the model background (J_b) and observations (J_o).



$$\mathbf{x}_a = \text{Arg min} J$$

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}-H[\mathbf{x}])^T\mathbf{R}^{-1}(\mathbf{y}-H[\mathbf{x}])$$

$$= J_b(\mathbf{x}) + J_o(\mathbf{x})$$

forecast

observation

observation operator

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{A}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

analysis

averaging kernel

Vertical Sensitivity of AC retrievals

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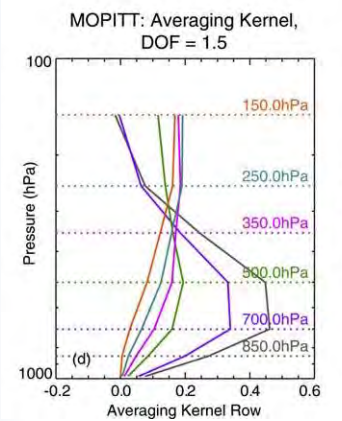
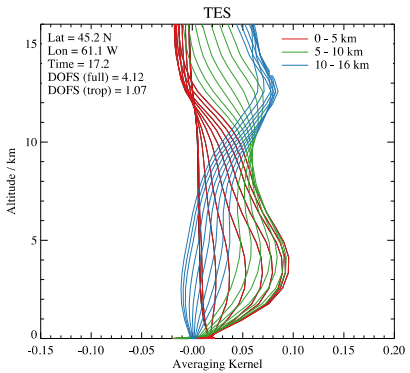
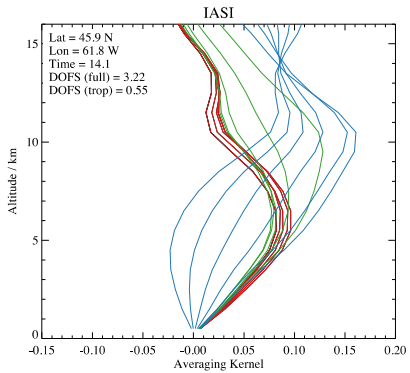
- Averaging kernels provide the information required to directly compare satellite retrievals with models/in situ observations.



MOPITT CO



TES O_3



IASI O_3

- Data assimilation into NWP models redistributes atmospheric composition observations to provide vertical information.
  - Validation against independent data is essential!

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CAMS SYSEM OVERVIEW

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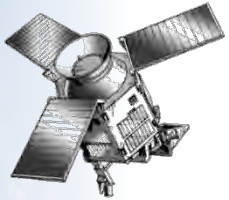
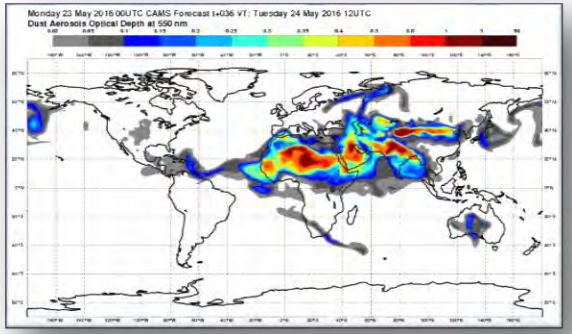
Space Agencies

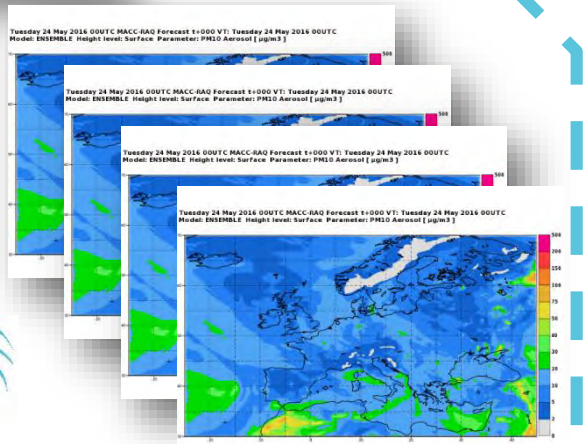




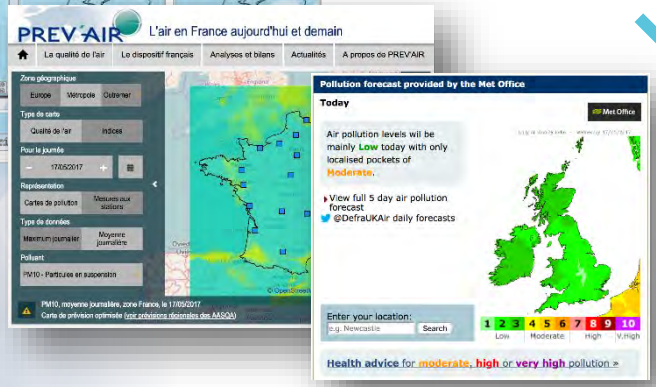
ECMWF/IFS

In-situ observations

7+2 regional CTMs



National scale



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DATA IS FULLY OPEN AND FREE-OF-CHARGE

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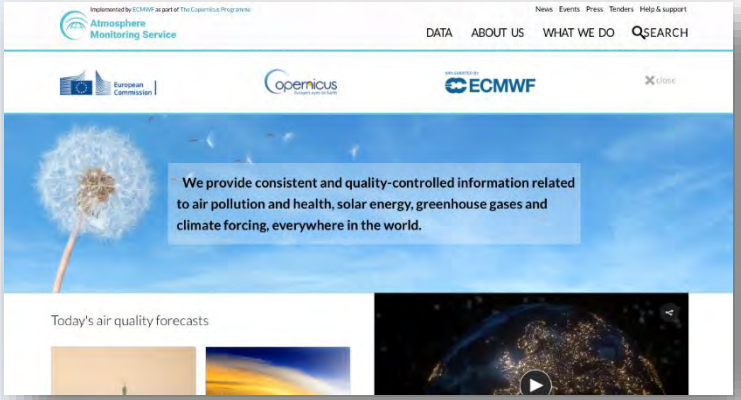
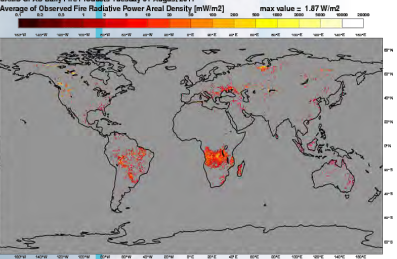
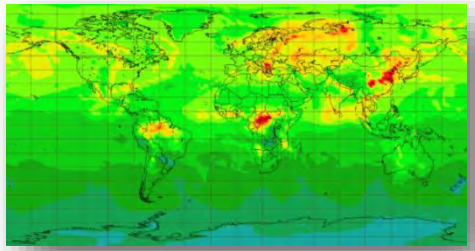


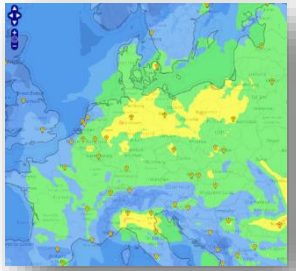
Bottom-up emissions and surface fluxes of greenhouse gases



Global fore emissions bases on satellite FRP products

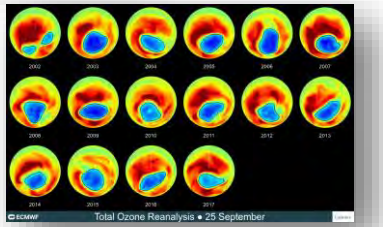


Global analyses, forecasts and reanalyses (2003-...)

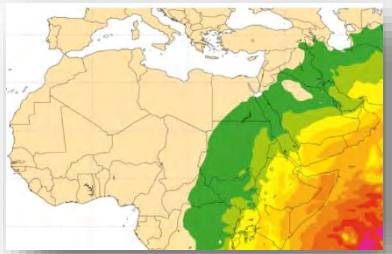


European Air Quality and products in support of policy users

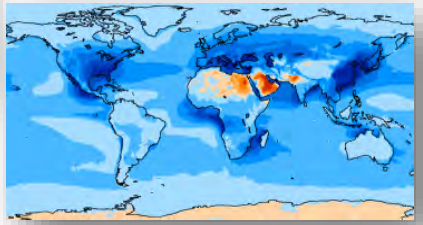
Ozone layer



Climate forcings



Solar radiation and UV index



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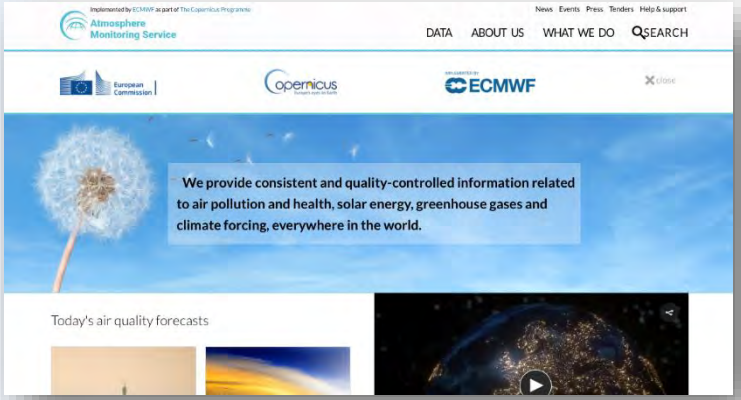
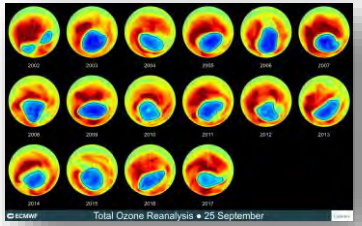
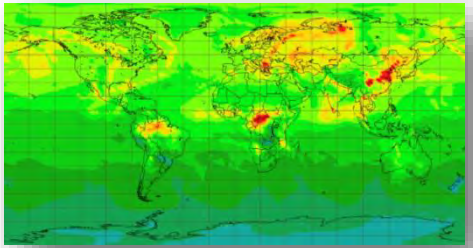
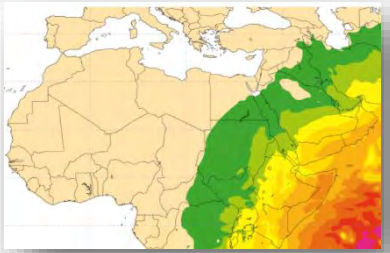


Ozone layer





Global analyses, forecasts and reanalyses (2003-...)



UV index

GLOBAL PRODUCTS

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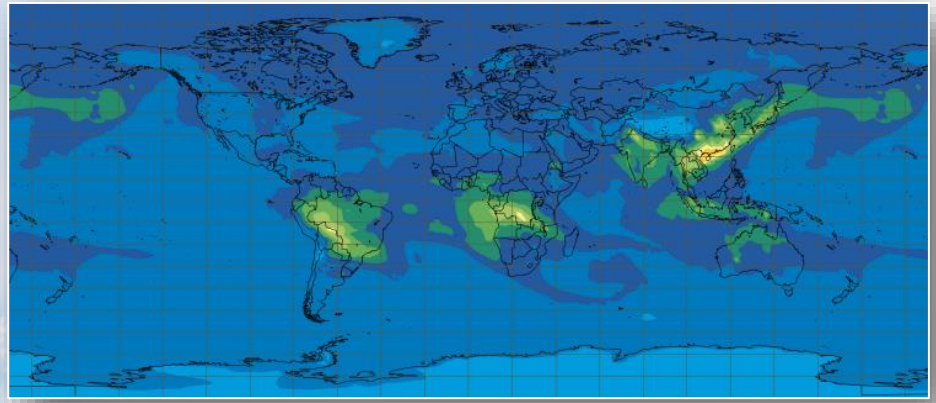
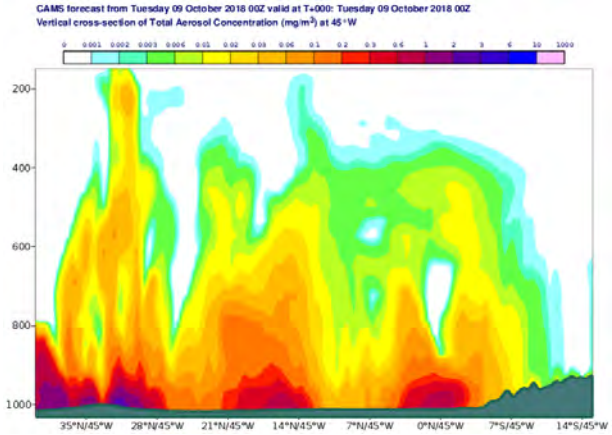
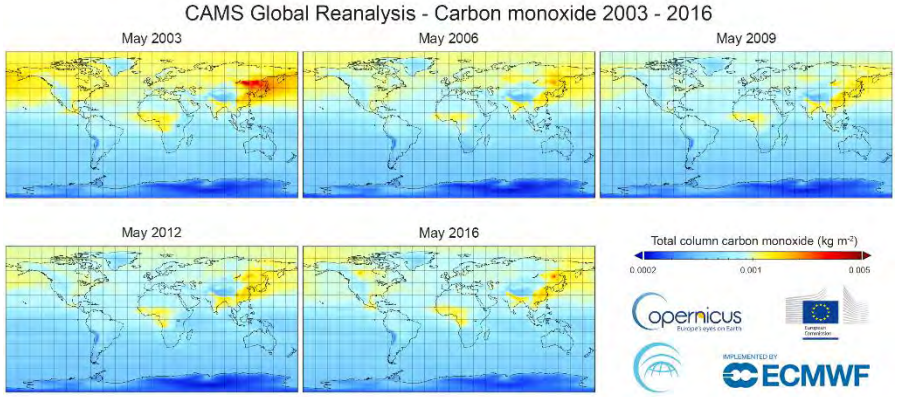




- Real-time analyses and D+5 forecasts at ~40km resolution
- Reanalysis 2003-… at ~80km resolution
- Dedicated forecasts (e.g., field campaign support, special events)



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Assimilated Satellite Observation CAMS Reanalysis

Retrievals assimilated in the CAMS RA between 2003 and 2016. In red are shown retrievals for which no averaging kernels were used, in green those where averaging kernels were use.

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Impact of NO2 assimilation (GOME-2, OMI, SCIA)

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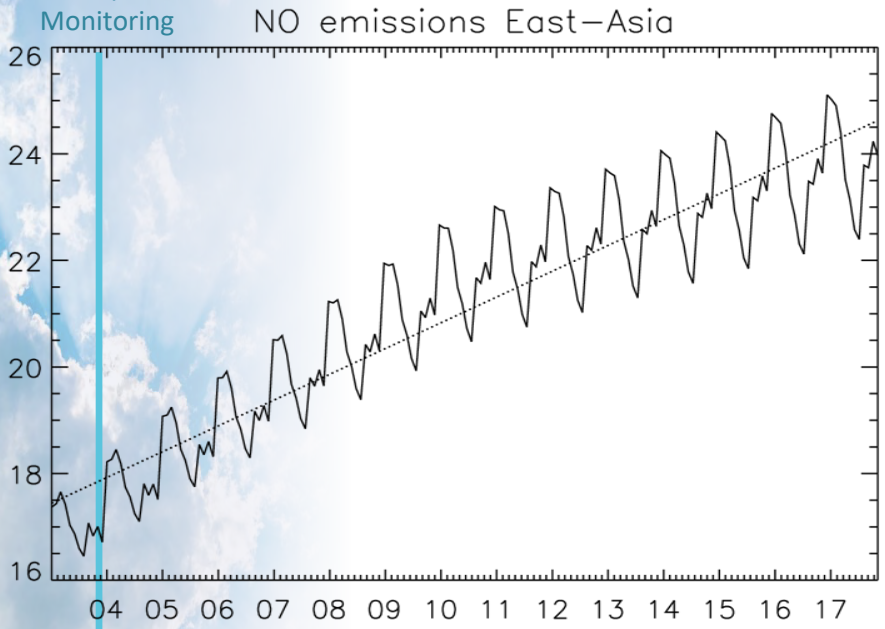
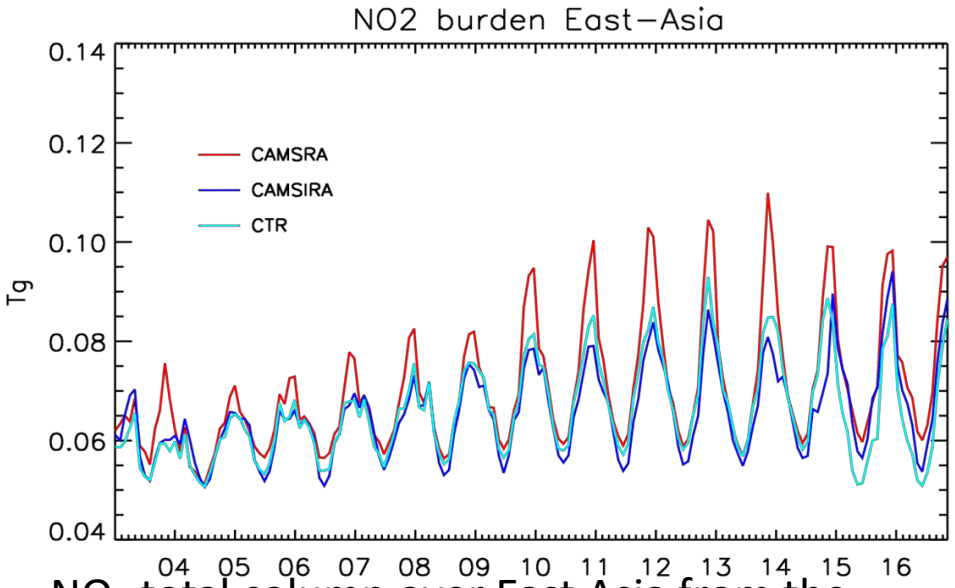


Time series of anthropogenic (Maccity) NO emissions over East-Asia



NO_2 total column over East Asia from the CAMS-RA (red), the control run (cyan, no composition DA) the CAMS interim RA (blue). Only the CAMS RA (NO_2 assimilation) shows a decrease of mean NO_2 after 2013.

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CAMS interim reanalysis
Trends and significance (2003-2016)

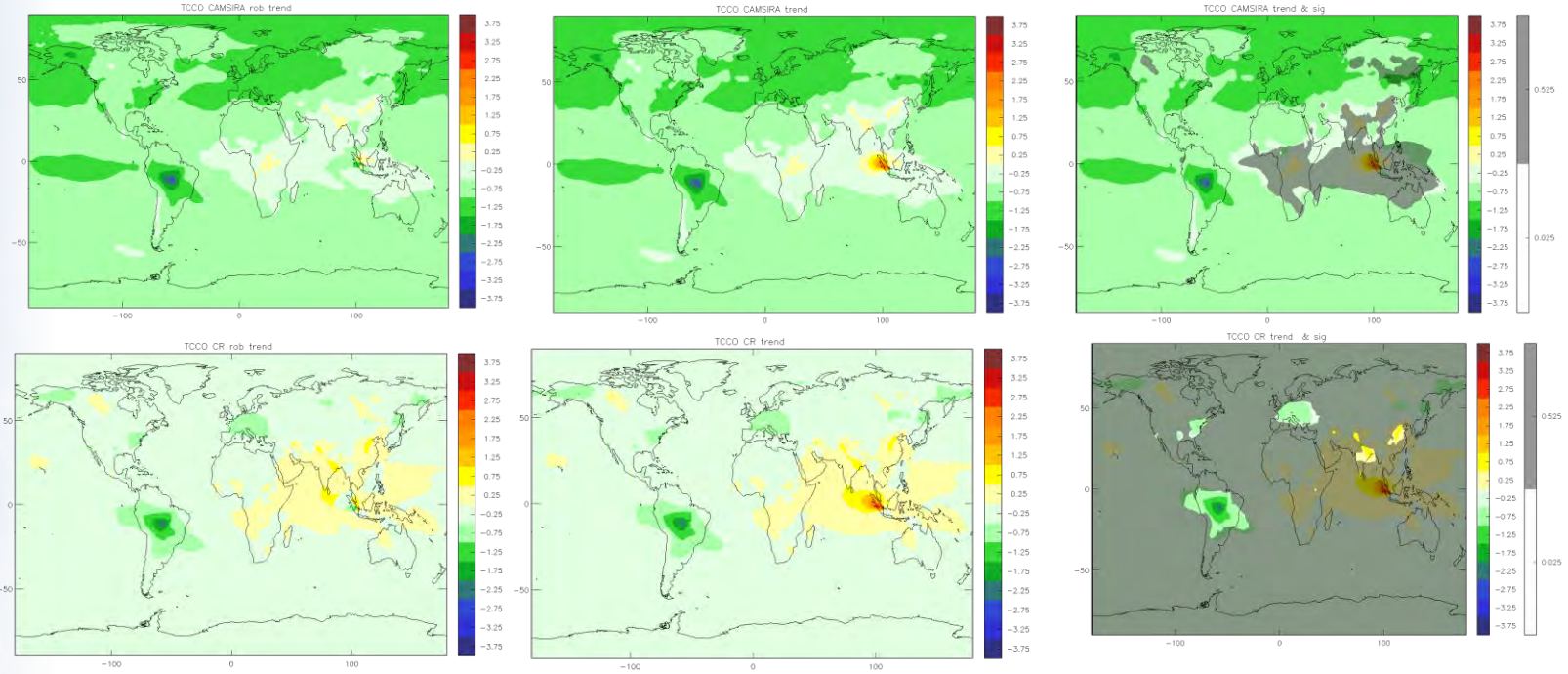
Robust linear trend %

Classic linear trend %

Classic linear trend & significance 95%

CAMSiRA (MOPITT + GFAS + MACCITY)

CR (MACCITY+GFAS)



- Trends in the CR (emissions) are less pronounced than in CAMSiRA (emissions & MOPITT).
- Global CO trends are about -1%/year in 2003-2016 period
- Negative trends mainly over North-America, Europe and South-America

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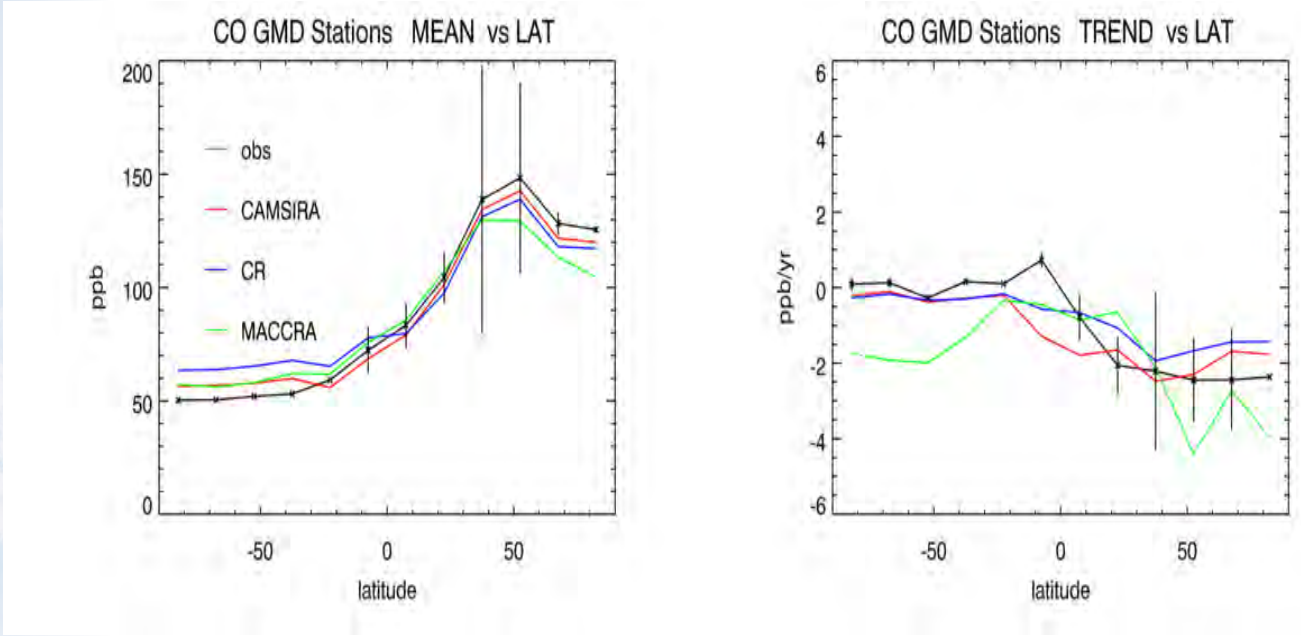
CO surface mean and trend



Mean

Trend (2003-2015)

Flemming et. al, 2017

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CAMS RA against observation in Izana

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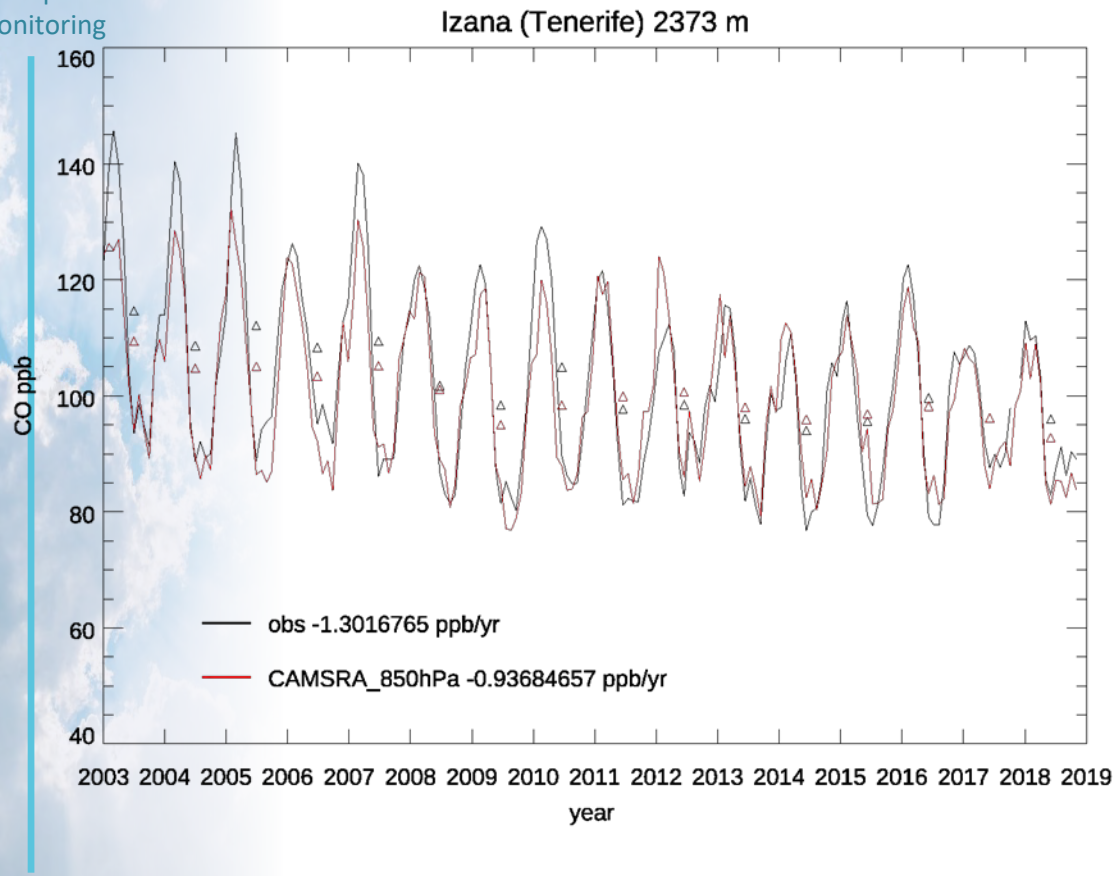

Monthly mean observed CO at Izana observatory on the Tenerife Island (2337 m a.s.l.) and the corresponding value from CAMS reanalysis. The legend shows the linear trend and its uncertainty over the period since 2003.

CAMS continued till present day

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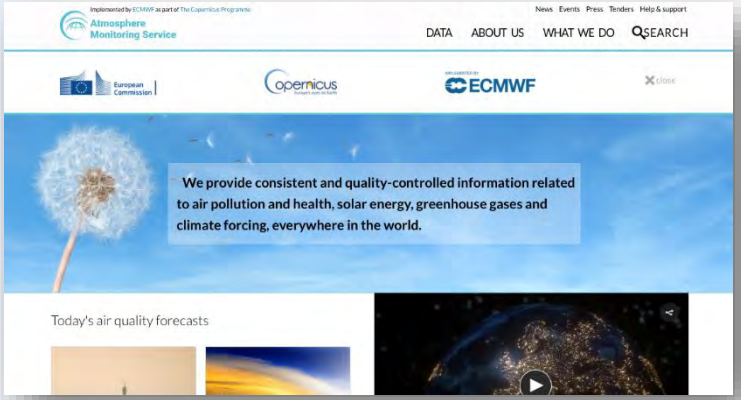

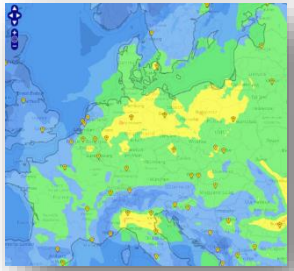

European Air Quality and products in support of policy users

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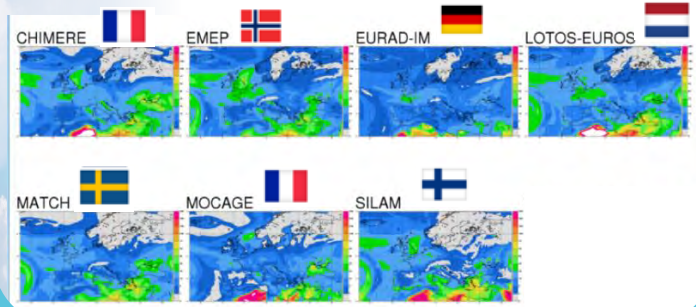
CAMS EUROPEAN AIR QUALITY PORTFOLIO

Based on a multi-model approach (same boundary conditions, same emissions, same meteo, assimilation of 1000+ surface observations for key species)

Individual operational AQ models



DEHM (AARHUS University)

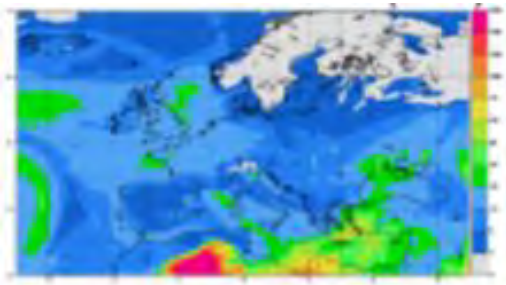
GEM-AQ (IEP)

MINNI (ENEA)

MONARCH (BSC)

Operational AQ ensemble

(incl. spread/uncertainty)



- Once daily D+4 forecasts
- Regulatory pollutants and pollens
- Annual reanalyses
- ~ 10km resolution

http://regional.atmosphere.copernicus.eu

(Presentation by M. Sofiev)

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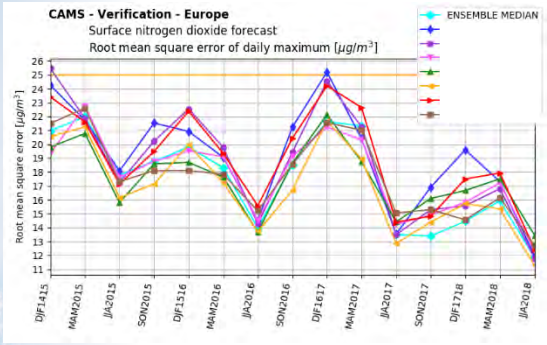
NO_2

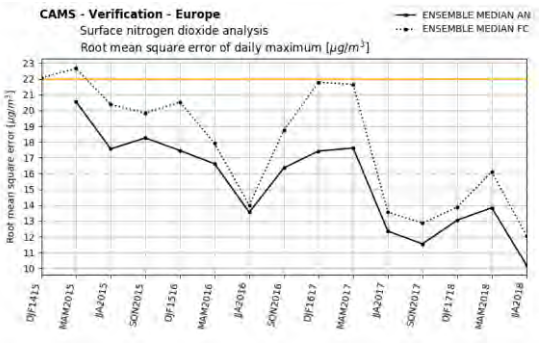
HIGH QUALITY PRODUCTS AT THE SCALE OF EUROPE

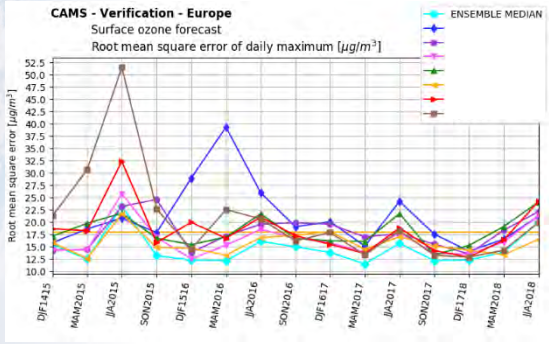
Atmosphere Monitoring

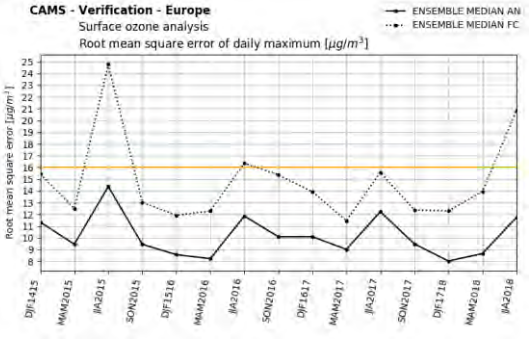
NO_2

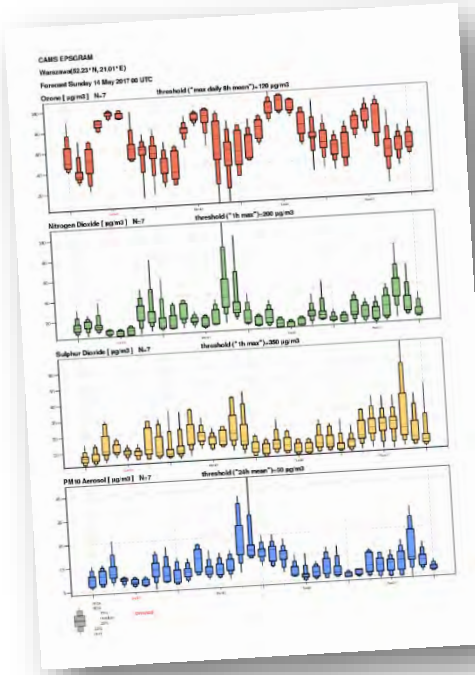
Ozone











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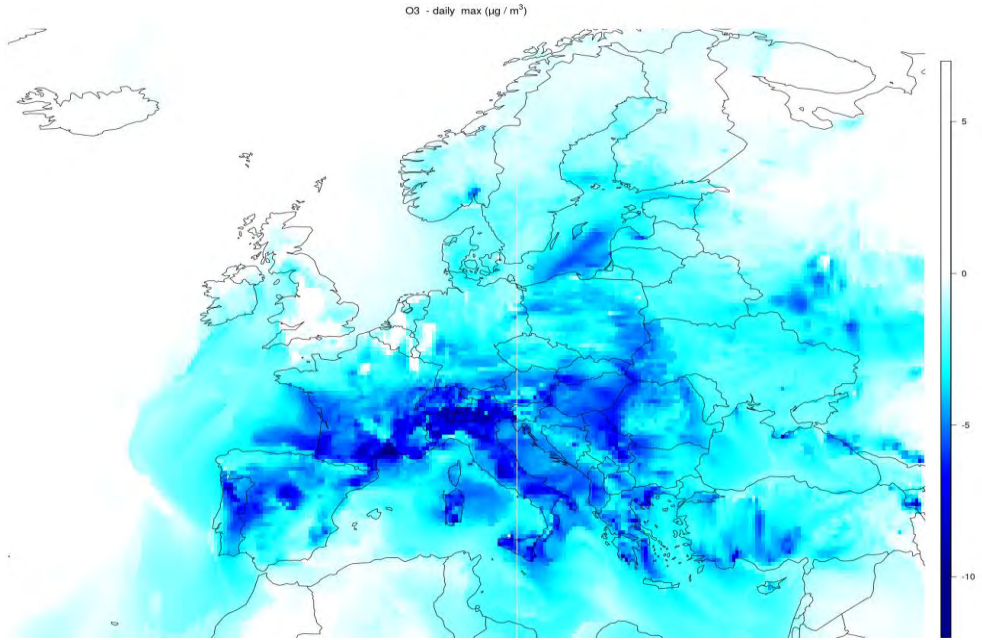
PRODUCTS IN SUPPORT OF POLICY USERS

Atmosphere Monitoring

Assess the effect of emission reductions on daily forecasts

CAMS_ACT : O3, PM10 (PM2.5 coming)



http://policy.atmosphere.copernicus.eu/CAMS_ACT.html

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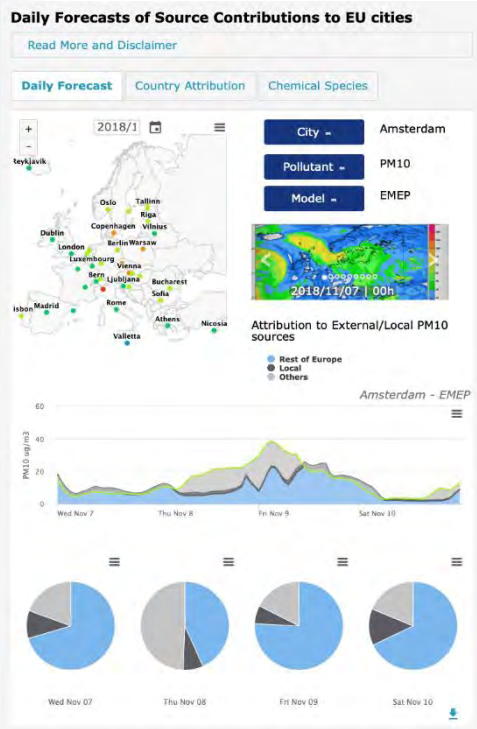
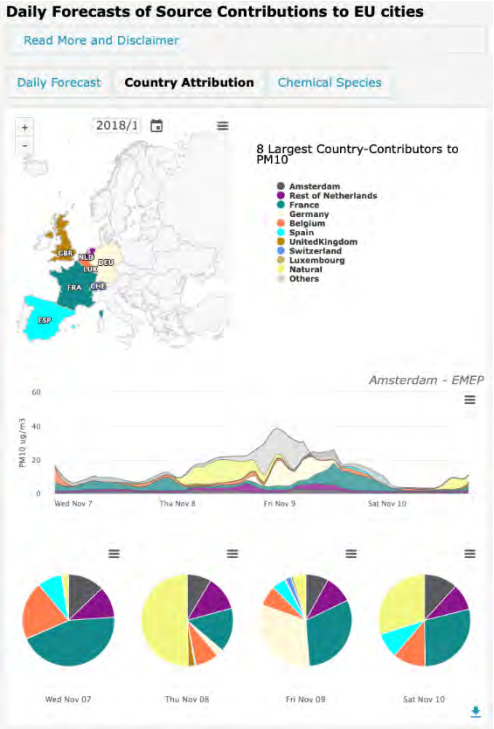
European Commission

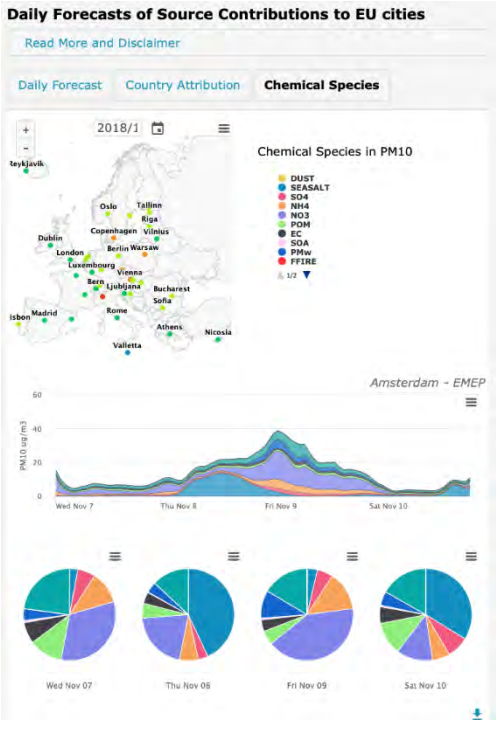
PRODUCTS IN SUPPORT OF POLICY USERS

Atmosphere Monitoring

Experimental: local vs imported, geographical origin, chemical speciation







http://policy.atmosphere.copernicus.eu/DailySourceAllocation.html

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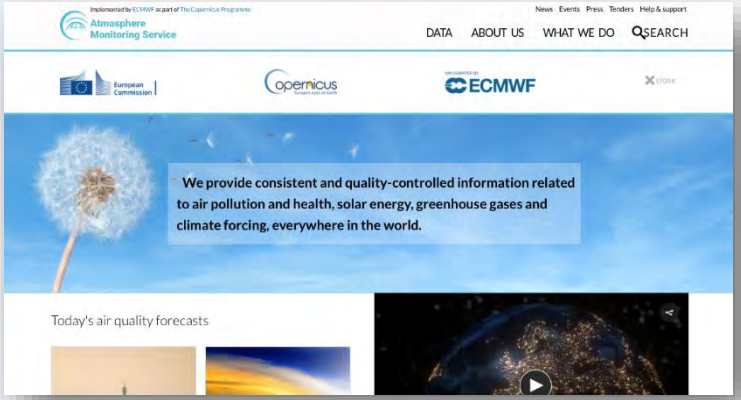
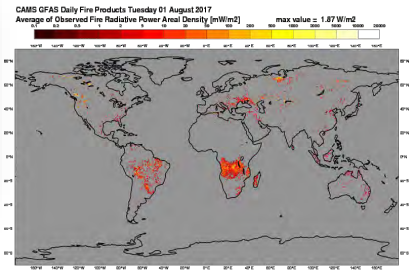
atmosphere.copernicus.eu

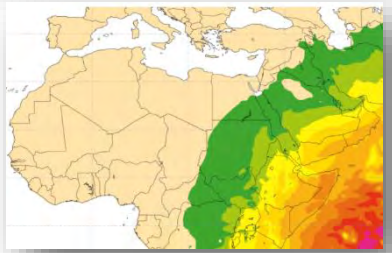
Atmosphere Monitoring



Bottom-up emissions and surface fluxes of greenhouse gases

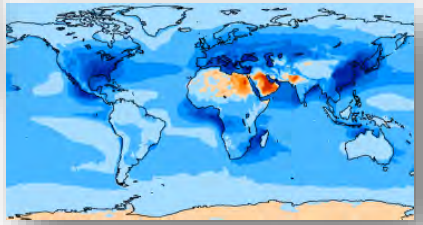


Global fore emissions bases on satellite FRP products



Solar radiation

Climate forcings



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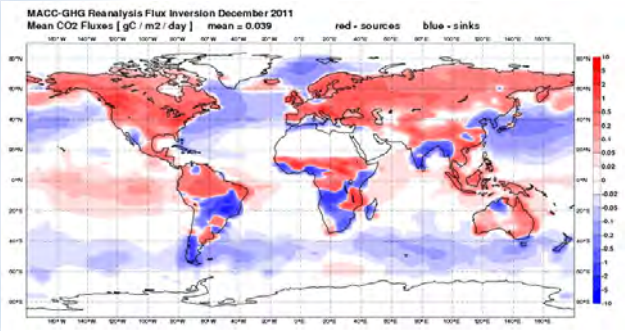
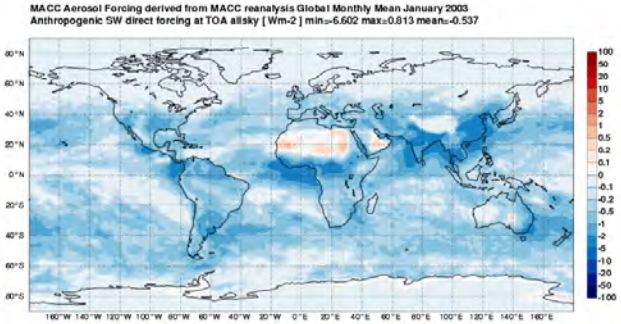
Atmosphere Monitoring

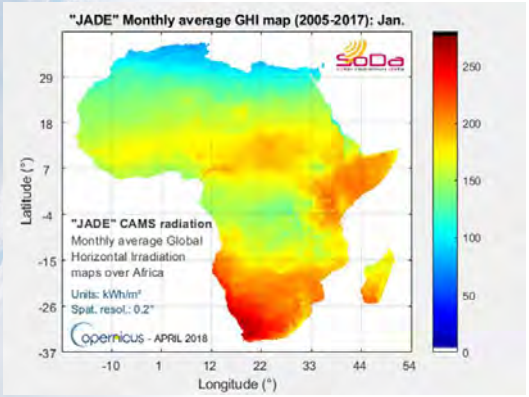
SUPPLEMENTARY PRODUCTS

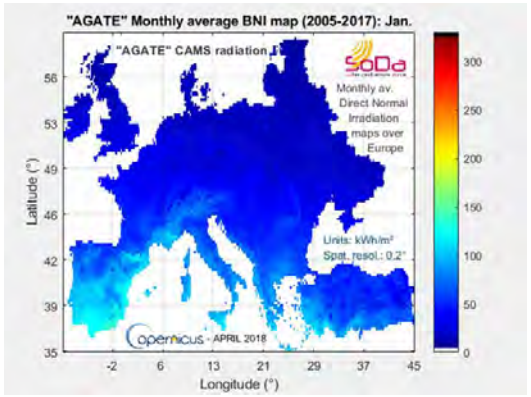




Greenhouse gas fluxes (CO_2, CH_4, N_2O)

Climate forcings





Solar radiation

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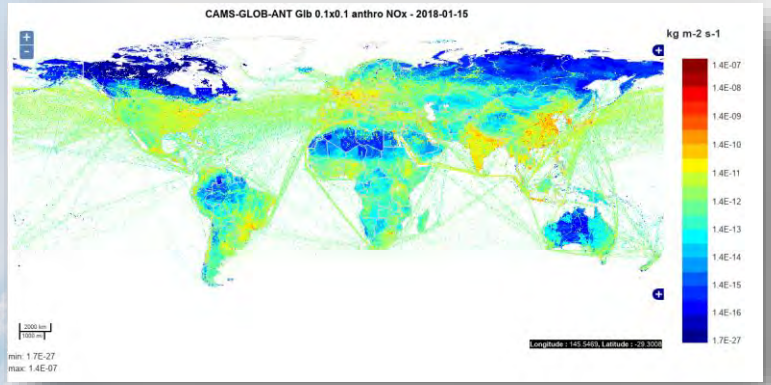
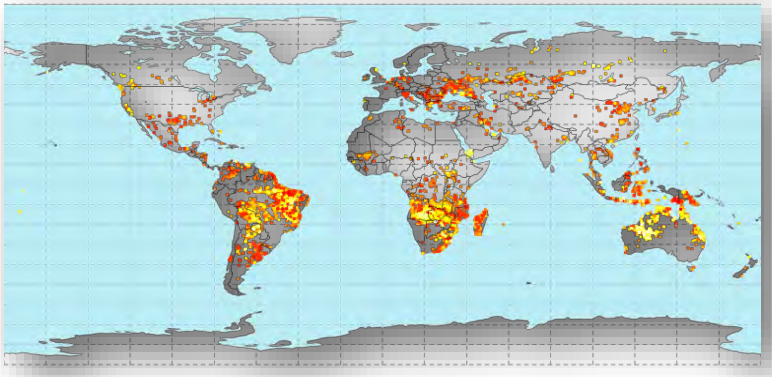
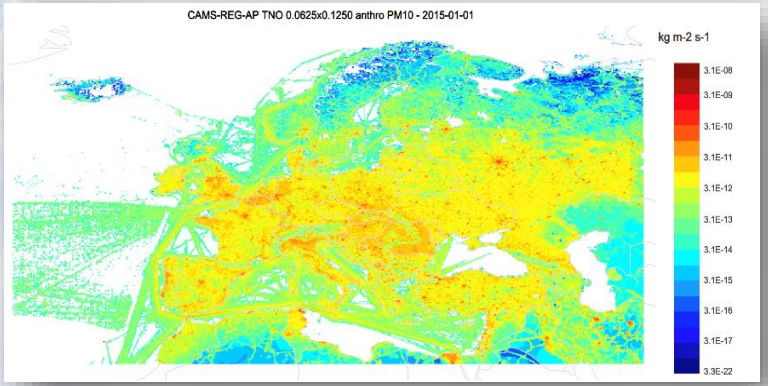
CAMS EMISSION PRODUCTS

Atmosphere Monitoring







- Fire emissions
- Global anthropogenic emissions
- Regional anthropogenic emissions
- Natural emissions

(Presentation by J. Keunen)

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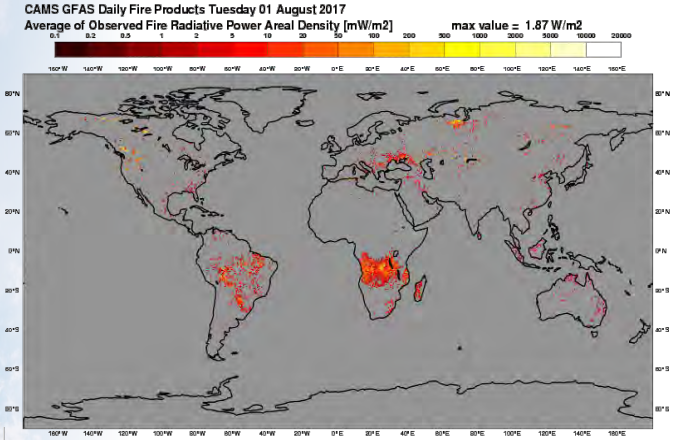
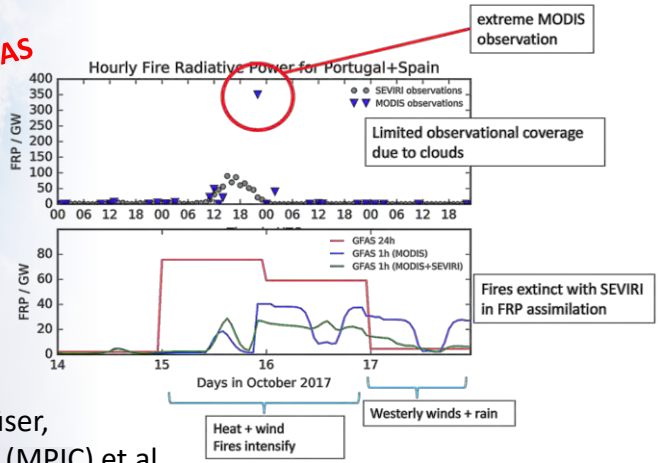
ESTIMATING GLOBAL WILDFIRE EMISSIONS IN CAMS

Atmosphere Monitoring



Upcoming hourly GFAS



c/o I. Hüser, J. Kaiser (MPIC) et al.

- Global Fire Assimilation System (**GFAS**); see http://apps.ecmwf.int/datasets/data/cams-gfas/
- Uses satellite observations of Fire Radiative Power (FRP)
  - Currently Aqua and Terra MODIS FRP observations
  - FRP from VIIRS, Sentinel-3 and geostationary satellites will be included in 2018
- Daily global coverage at ~10km resolution
  - 1-day behind NRT (diurnal cycle/hourly output coming operational in 2018)
- Emissions of aerosols and gases are estimated using factors dependent on vegetation type.
- Injection heights calculated with Plume Rise Model and IS4FIRES.

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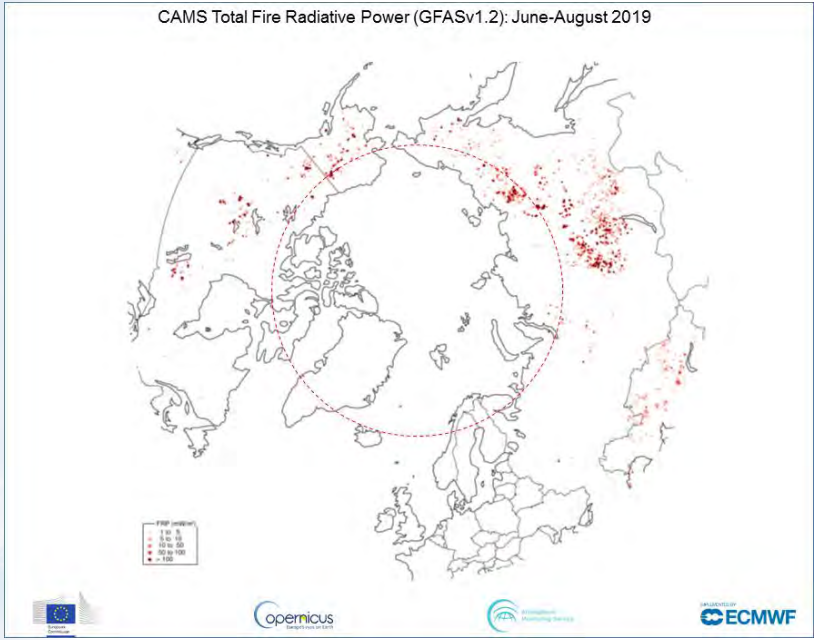
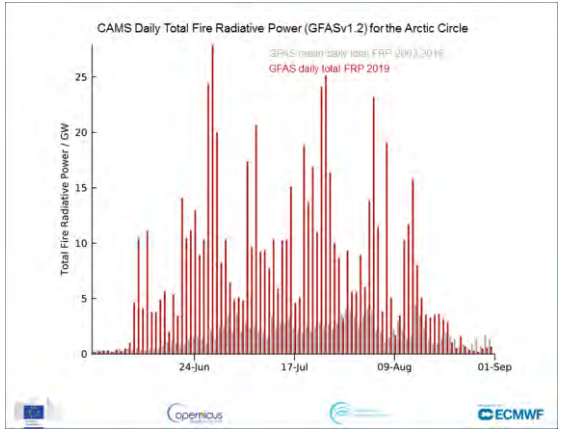
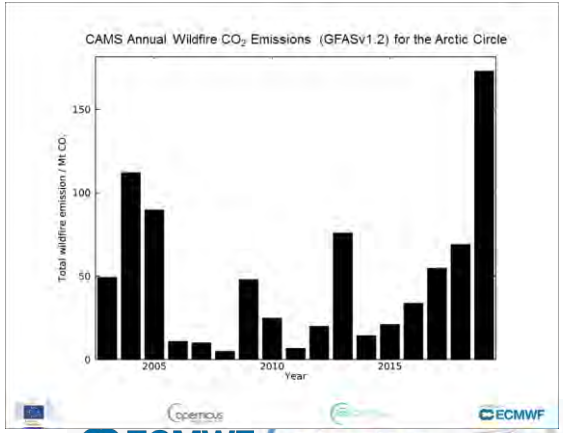
Monitoring Arctic wildfires during summer 2019

Atmosphere Monitoring







- Daily total wildfire emissions were well above the 2003-2018 average throughout the summer north of the Arctic Circle
- Many wildfires concentrated in the Sakha Republic, Russia with other fire activity in Alaska, Yukon Territory and Greenland
- Total estimated equivalent CO2 of ~170 megatonnes

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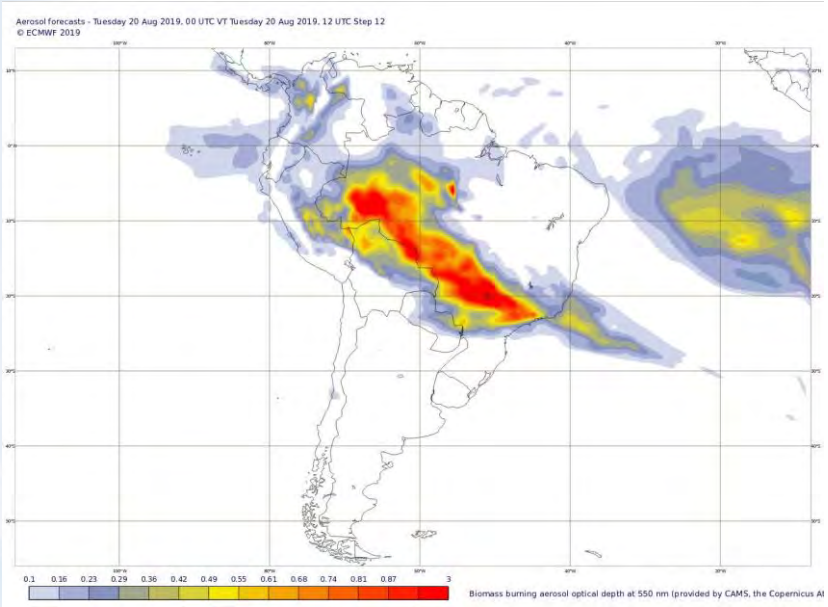
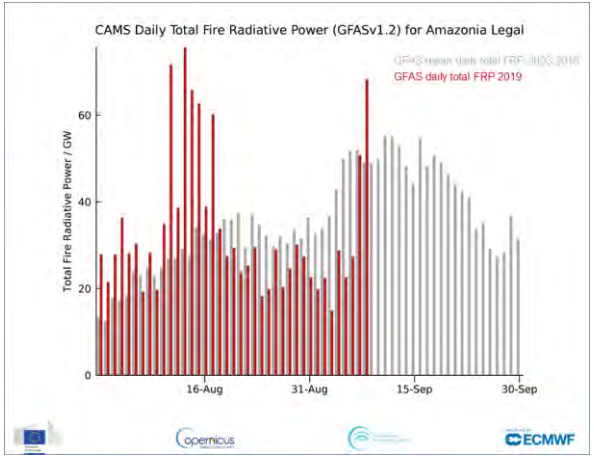
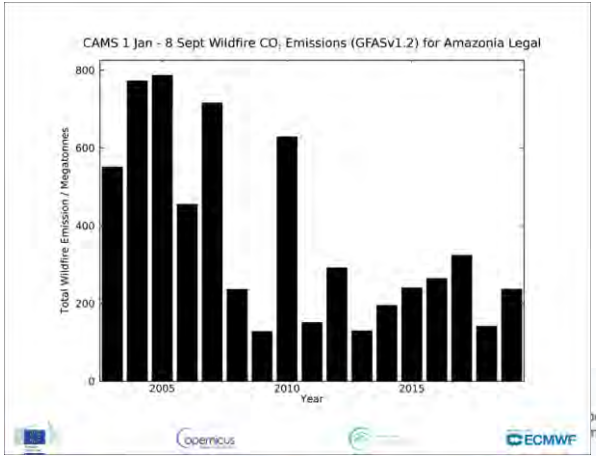
Monitoring Amazon fires in August 2019

Atmosphere Monitoring



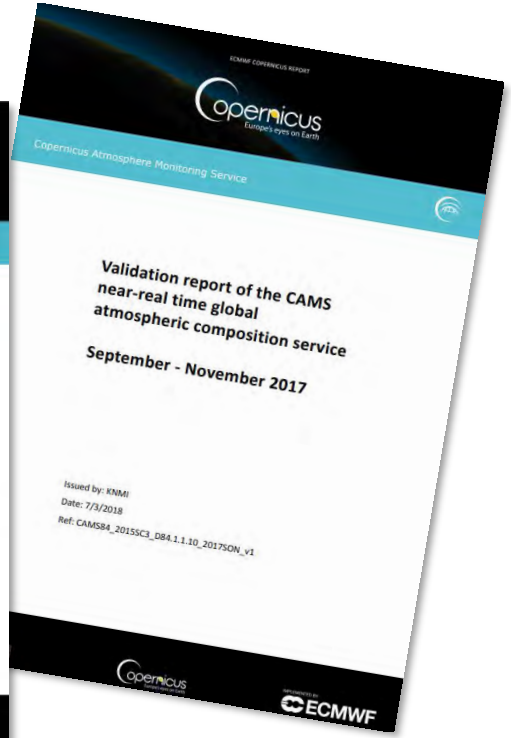


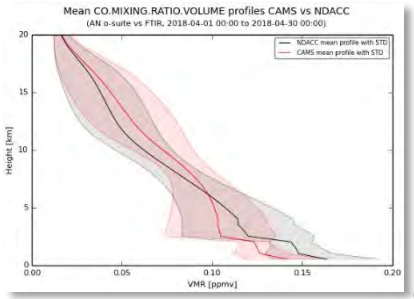


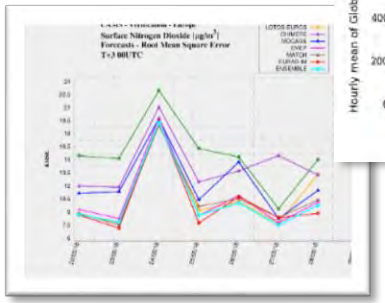
- Above average daily fire activity during first 2 weeks of August across the main states of the Brazilian Amazon (also in Bolivia and Paraguay) with smoke predicted by CAMS across much of southern Brazil
- Below average (2003-2018) daily activity through second half of August shows annual total (to 8 September) is not particularly high compared to previous years in GFAS dataset.

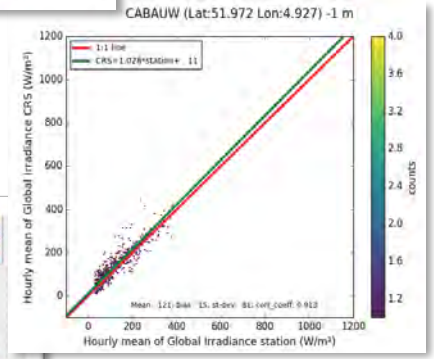
DOCUMENTATION & QUALITY CONTROL

Atmosphere Monitoring









CAMS provides detailed information about how its products are produced and what the quality is

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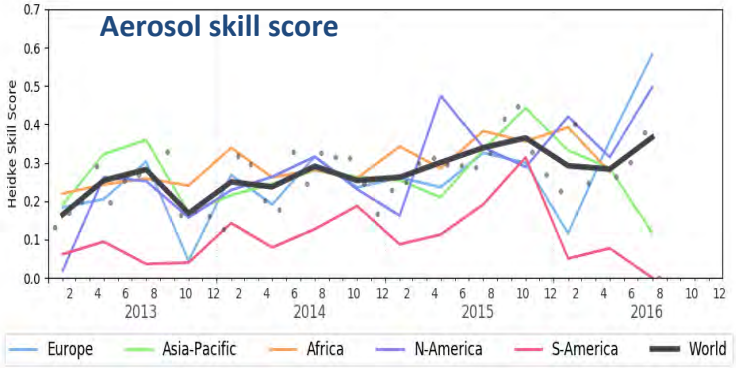
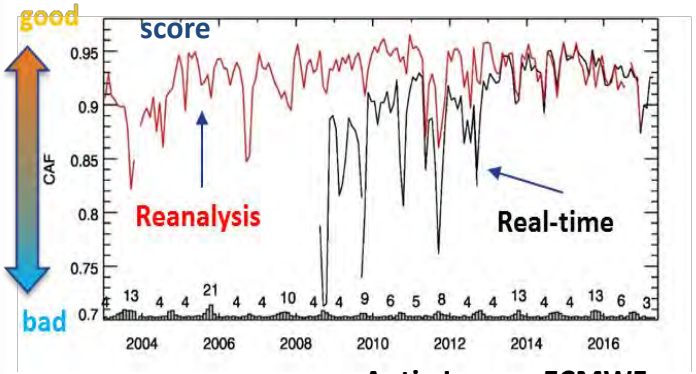
IMPROVMENTS of GLOBAL CAMS Forecast

Atmosphere Monitoring



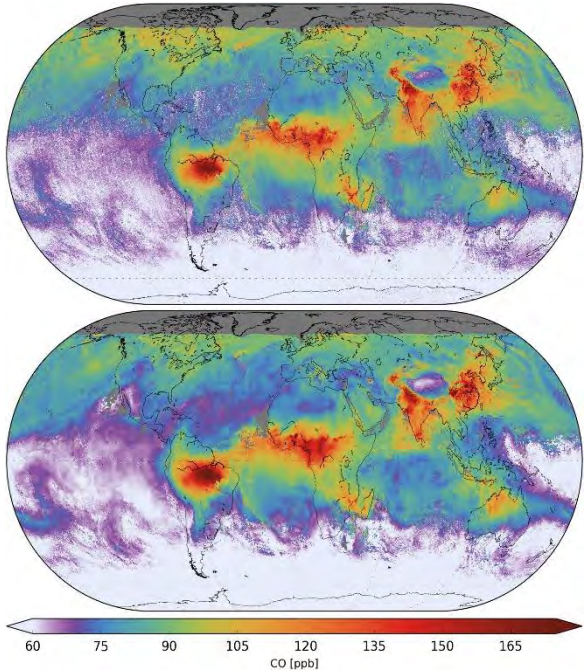
Michael Schulz, MetNo

Ozone skill score



Antje Inness, ECMWF

Carbon monoxide
Sentinel-5p observations (top) vs
CAMS model (bottom)



Borsdorff et al., JRL, 2018

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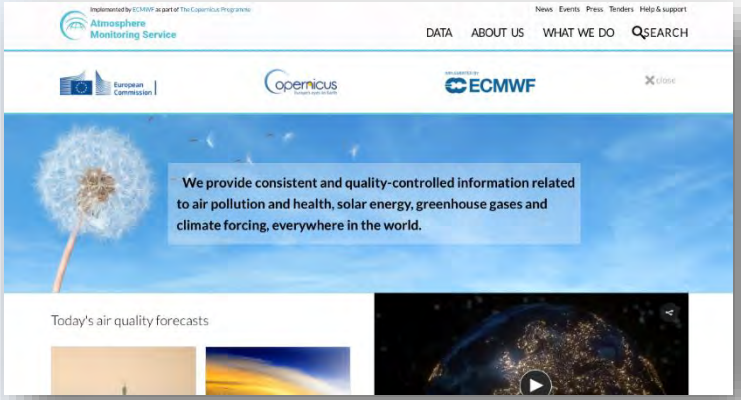
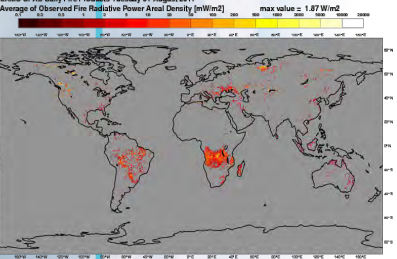
DATA IS FULLY OPEN AND FREE-OF-CHARGE

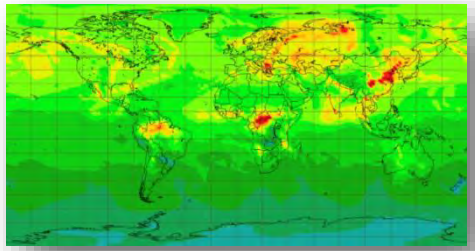
Atmosphere Monitoring



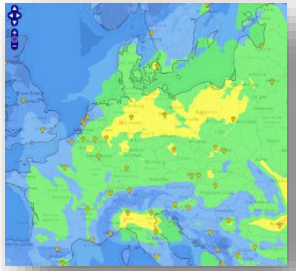
Bottom-up emissions and surface fluxes of greenhouse gases



Global fore emissions bases on satellite FRP products

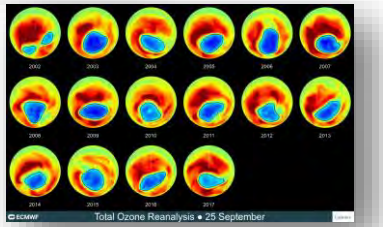


Global analyses, forecasts and reanalyses (2003-...)

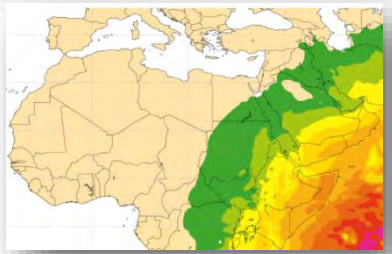


European Air Quality and products in support of policy users

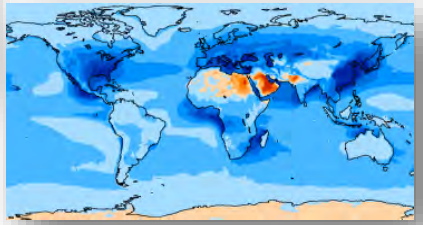
Ozone layer



Climate forcings



Solar radiation and UV index



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GLOBAL CAMS PRODUCTS for AQ in Africa

- 2x 5 day global CAMS Forecast (aerosol & chemistry)
  - 40 x 40 km, 137 levels, lowest level extent 20 m
- Global CAMS re-analysis (aerosol & chemistry)
  - 80 x 80 km, 60 levels, lowest level extent 20 m
  - 2003 – 2018, 2019 (1 month delay)

Boundary Conditions

- GFAS fire emissions for (0.1 degree) for many species
- CAMS_GLOB anthropogenic, biogenic and natural emission

Emission Input

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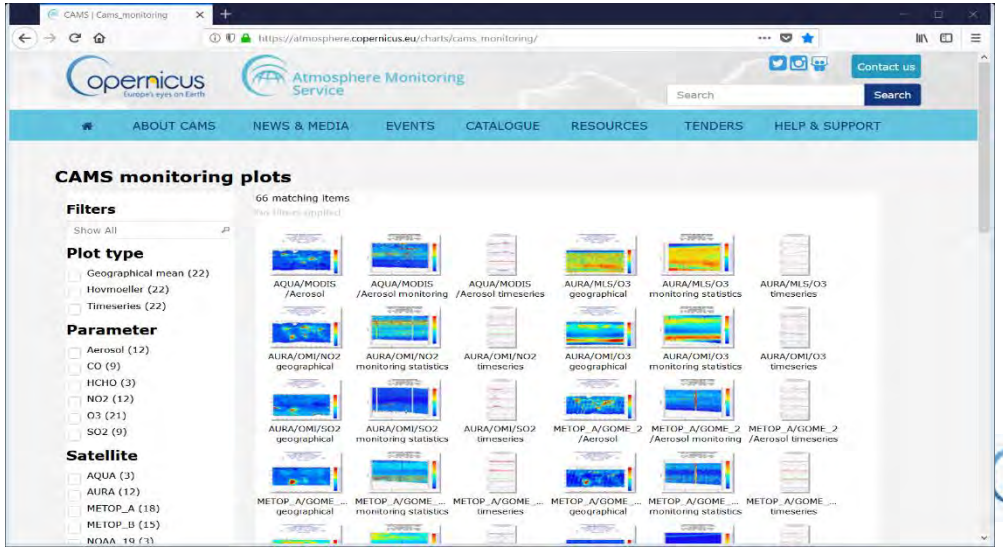
Summary

- TROPOMI/Sentinel-5P are monitored by CAMS
- O3 data have been operationally assimilated since Dec 2018
- Assimilation tests with NO2, CO and SO2 are under way
- Monitoring plots on: atmosphere.copernicus.eu/charts/cams_monitoring/



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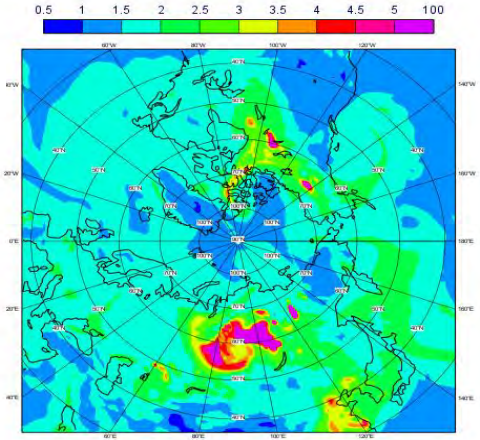
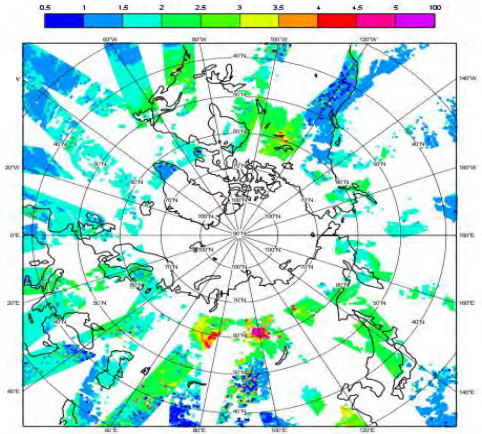
Total column CO on 22 July 2019

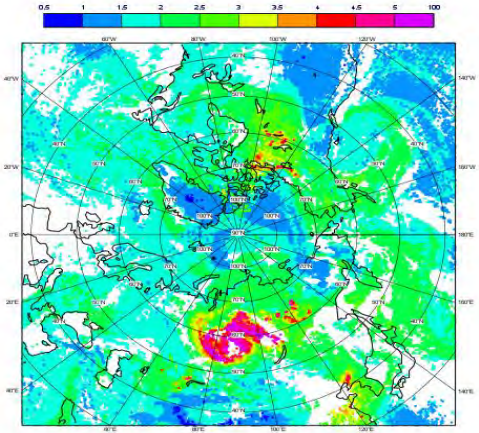
CAMS analysis (12z)



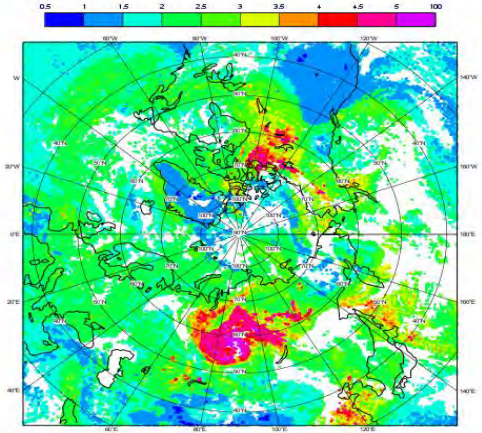
MOPITT



TROPOMI



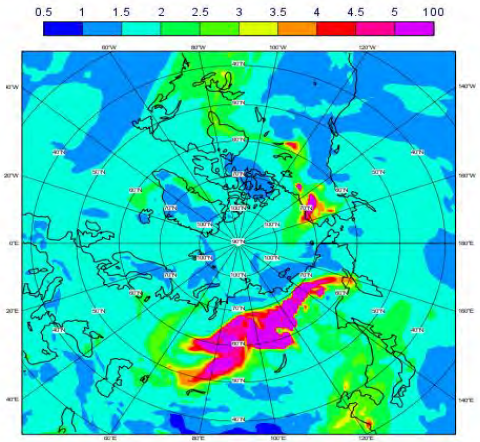
IASI-A & B



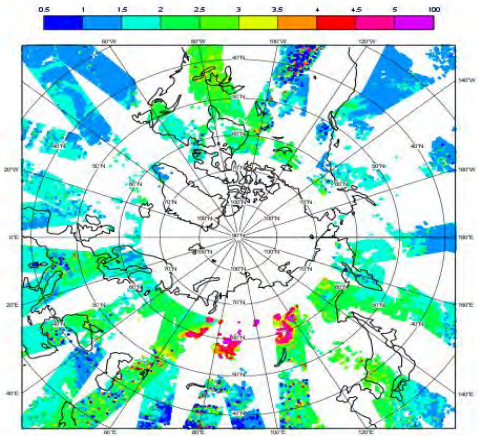
Units: 10^{18} molec/cm^2

Total column CO on 25 July 2019

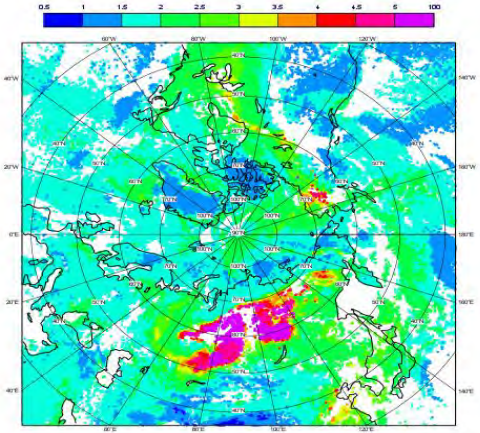
CAMS analysis (12z)



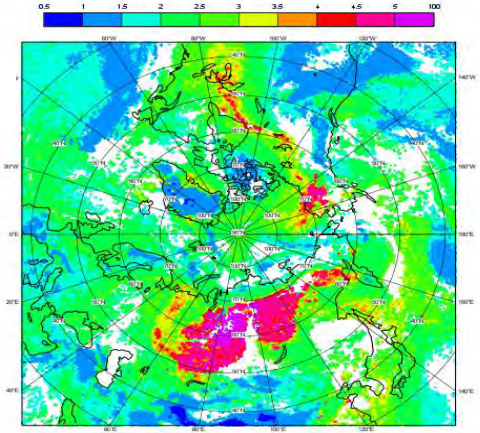
MOPITT



TROPOMI

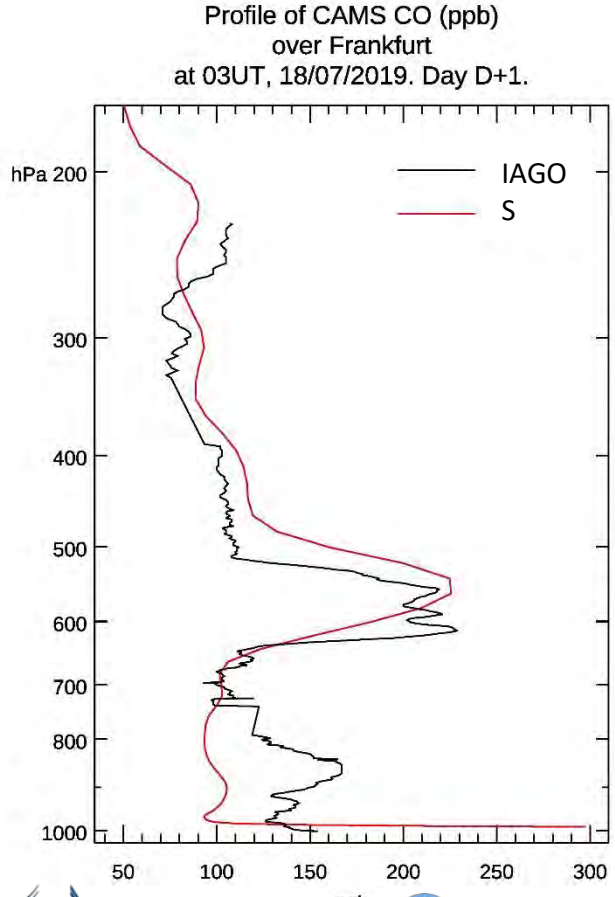


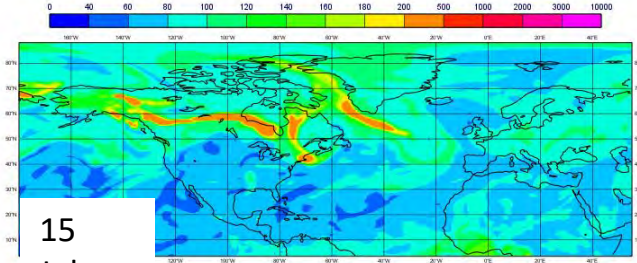
IASI-A & B



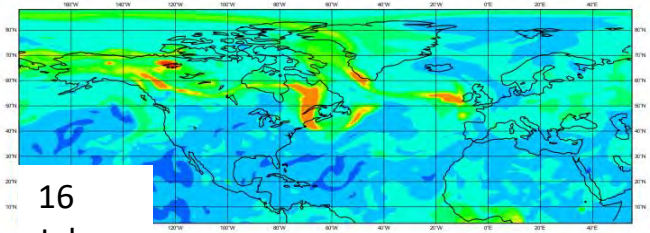
Units: 10^{18} molec/cm^2

CO transport form North American fires in July 2019

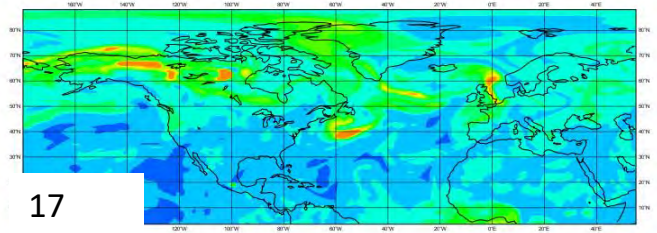




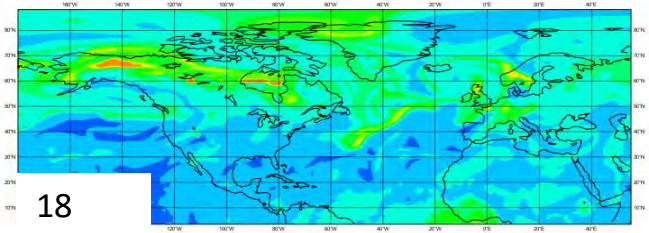
15 July



16 July



17 July



18

Units: ppb

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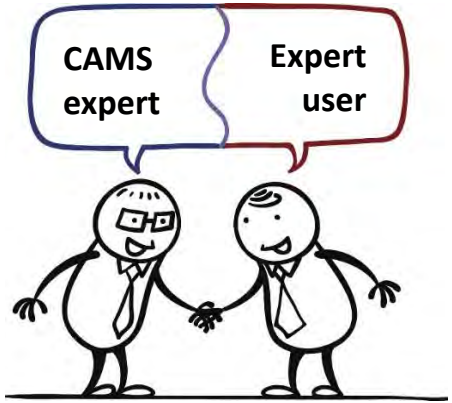
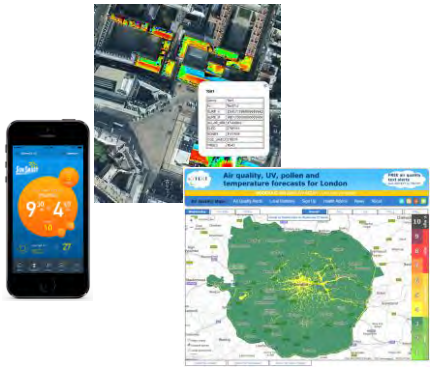
Atmosphere Monitoring

CAMS: BIG DATA FOR LOCAL APPLICATIONS

CAMS provides big data with the corresponding technical and scientific expertise to support expert users.
In doing so, we allow the CAMS information to reach millions of users in and outside Europe.





Downstream applications

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